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Article

Local Knowledge about Ecosystem Services Provided by Trees in Coffee Agroforestry Practices in Northwest Vietnam

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Abstract: In recent decades in northwest Vietnam, Arabica coffee has been grown on sloping land in intensive, full sun monocultures that are not sustainable in the long term and have negative environmental impacts. There is an urgent need to reverse this negative trend by promoting good agricultural practices, including agroforestry, to prevent further deforestation and soil erosion on slopes. A survey of 124 farmers from three indigenous groups was conducted in northwest Vietnam to document coffee agroforestry practices and the ecosystem services associated with different tree species used in them. Trees were ranked according to the main ecosystem services and disservices considered to be locally relevant by rural communities. Our results show that tree species richness in agroforestry plots was much higher for coffee compared to non-coffee plots, including those with annual crops and tree plantations. Most farmers were aware of the benefits of trees for soil improvement, shelter (from wind and frost), and the provision of shade and mulch. In contrast, farmers had limited knowledge of the impact of trees on coffee quality and other interactions amongst trees and coffee. Farmers ranked the leguminous tree species *Leucaena leucocephala* as the best for incorporating in coffee plots because of the services it provides to coffee. Nonetheless, the farmers' selection of tree species to combine with coffee was highly influenced by economic benefits provided, especially by intercropped fruit trees, which was influenced by market access, determined by the proximity of farms to a main road. The findings from this research will help local extension institutions and farmers select appropriate tree species that suit the local context and that match household needs and constraints, thereby facilitating the transition to a more sustainable and climate-smart coffee production practice.

Keywords: agroforestry coffee; ecosystem services; shade tree species; pairwise ranking; Vietnam

1. Introduction

Coffee is the one of the most important commodities globally and contributes to the income of millions of smallholder farmers. Approximately twenty-five million farmers grow coffee in sixty developing countries [1]. There are approximately 10.5 million ha of coffee around the world consisting of both Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*) varieties [2]. Vietnam is the second largest world producer after Brazil [3]. It is also the largest producer of Robusta coffee, accounting for 14.5% of global production and a share of about 40% of global trade [4].

Coffee was first introduced to Vietnam by the French in 1857. Between 1975 and 2010, the area of coffee planted in Vietnam increased from 134,000 ha to 513,000 ha. By 2016, the total area of coffee had

reached 650,000 ha [5]. Vietnam exports over 90% of its total production but the value remains low mainly because low-quality beans rather than processed coffee are exported at a low price. The annual export volume was approximately 1.8 million tons with a value of USD 3.5 billion in 2018 [6].

Whilst Robusta is the most popular coffee variety grown in Vietnam, it is mainly Arabica that is cultivated in mountainous areas, generally at elevations above 600 m above sea level (masl). Arabica production accounts for approximately 7% of the total coffee area of Vietnam [7], including approximately 3995 ha in Dien Bien [8] and 17,128 ha in Son La [9] provinces in 2018.

Smallholder farmers have converted large areas of annual crops to coffee in northwest Vietnam, which has transformed their livelihoods from subsistence to commercial commodity dependent [10]. Most of the Arabica plantations in the northwest are full sun monoculture on sloping land, which is not sustainable in the long term because of soil degradation. The long-term sustainability of unshaded coffee is likely to be limited given climate change, resulting in higher temperatures and more variable weather patterns. Increasing temperatures, uneven precipitation and increased frequency and severity of extreme weather events such as storms, floods or frost may have negative impacts on Arabica coffee production.

Coffee was originally cultivated under moderate to heavy shade in Ethiopia, which was gradually changed over much of the area, grown under light or no shade to increase coffee yield, at least in the short term. However, reducing shade in coffee plots makes them more vulnerable to water run-off [11] and soil erosion [12] biodiversity loss [13] and climate change [14]. Shade coffee, which is a form of agroforestry where coffee is cultivated under a tree canopy [15], is generally considered to be more environmentally friendly. Studies have shown increased biodiversity, higher levels of natural pollination [16], greater erosion control, and higher carbon sequestration [13,17–19]. Boundary tree planting in coffee farms has potential for climate mitigation and adaptation [14,20].

Expanding the area of shaded coffee in Northwest Vietnam offers a potential mechanism to provide more sustainable cultivation, both economically and environmentally, when compared with either unshaded coffee or other monoculture crops such as maize. There has been an increased interest, globally, in shaded coffee given the sensitivity of coffee, particularly Arabica, to climate change [21,22]. Coffee cultivation, with between 20 to 40% shade and appropriate species and management, has been found to have a regulated microclimate which, in turn, leads to high coffee yield and quality [23]. However, poorly designed tree cover in coffee can lead to low coffee productivity [24]. Shade systems provide additional benefits beyond the direct impacts on coffee production in the shape of a more balanced supply of ecosystem services [25,26]. Shade trees in coffee can increase the sustainability of coffee production as well as the economic resilience of households to agricultural price volatility through production and revenue diversification. Furthermore, they facilitate the adaptation of rural communities to climate change via the adoption of more ‘climate-smart’ farming practices.

There have been a number of studies looking at farmers’ knowledge about coffee agroforestry [27–29] however, to date, there has been no study assessing farmers’ attitudes and knowledge associated with coffee agroforestry in northwest Vietnam. Understanding farmers’ knowledge of the benefits that trees potentially provide alongside any trade-offs or disservices is critical for developing interventions that enable more resilient landscapes [30], whilst reconciling production and conservation objectives. This is particularly important in the context of northwest Vietnam given the broad spectrum of ethnicities at play and the way in which factors such as gender might influence tree species selection.

To address this knowledge gap, the principal aim of this study was to explore farmers’ perceptions of the range of benefits associated with shade trees in coffee systems and then to use this information to customize a decision-support tool (the ‘Shade Tree Advice tool’ developed by researchers from World Agroforestry, French Agricultural Research Centre for International Development (CIRAD) and International Institute of Tropical Agriculture (IITA)) to local conditions in Vietnam. The original tool was developed using data from Uganda, Ghana and China; <http://www.shadetreeadvice.org> [31,32]. The ‘Shade Tree Advice’ tool is aimed primarily at extension services, members of farmers’ cooperatives and non-governmental organizations working in northwest Vietnam. The tool supports farmers in

selecting the most appropriate tree species that are both adapted to local ecological conditions and match household needs and constraints.

2. Materials and Methods

2.1. Study Sites

Son La and Dien Bien are the only two provinces in northwest Vietnam where coffee is planted, and Son La is the second largest Arabica coffee producer in Vietnam. This study was conducted in seven communes of Son La and Dien Bien (Figure 1). The criteria for commune selection were coffee planting area, ethnicity, proximity to main road to compare the different characteristics of coffee agroforestry practices, and willingness to share perceptions about tree services and tree species ranking. Information on these criteria were provided by district extension workers. The communes were selected from the most well known coffee planting areas in two provinces. Coffee agroforestry households were suggested by commune extension workers. As Thai, H'mong and Kinh are the major ethnic groups in the region, households from these three ethnicities that were actively involved in coffee agroforestry were selected for the surveys with specific care taken to ensure gender balance amongst interviewees. The Kinh are the largest ethnic group in Vietnam but account for less than 30% of the population in the northwest. Kinh people generally live at lower altitudes (below 600 m) while Thai people are generally found at altitudes of 500 to 800 m and H'mong people generally live in areas above 800 m. The proximity to main roads were categorized into three levels: 0–2, 2–5 km or further than 5 km. As farmers often sell their fruit products, such as mango or plum, along the main road, this represents an indicator of their proximity to markets.

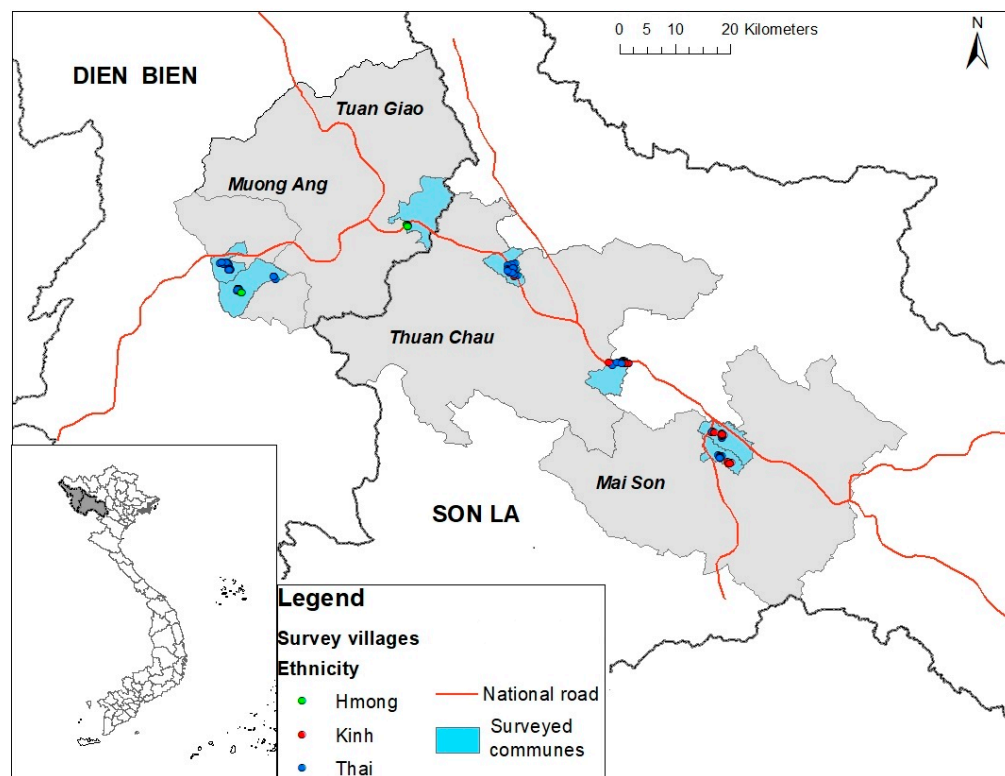


Figure 1. Map of the study sites and the communes surveyed in the Son La and Dien Bien provinces of northwest Vietnam.

The elevation of the study sites ranges from 300 to 2000 masl on 5 to 50% slopes. Annual temperature ranges from 21 to 24 °C, and annual precipitation ranges from 1500 to 2500 mm. Rainy season is from

April to September. The main soil type is Ferrasols, and average soil layer thickness ranges from 50 cm to 1 m. These natural conditions are favorable for Arabica coffee. The upper limit frost in winter is the most serious constraint for Arabica coffee cultivation at high elevations. In addition to coffee, the main agricultural land uses are annual crops (upland rice (*Oryza sativa*), maize (*Zea mays*), fruit tree plantations such as longan (*Dimocarpus longan*), plum (*Prunus salicina*), and mango (*Mangifera indica*). There are also limited areas of planted forest and secondary natural forest.

2.2. Data Collection

Data were collected through two rounds of surveys between March to May 2018, following a well established tree attribute ranking methodology [31,33]. The first survey consisted of a household interview and tree inventory in coffee agroforestry farms in March 2018. A total of 124 households were surveyed; consisting of 16 H'mong farmers, 25 Kinh farmers and 83 Thai farmers (with those proportions largely representative of the ethnic distributions at the study sites). Sixty-eight men and 56 women participated in the interview process. A sub-section of 50 farms were inventoried to provide a baseline of potential shade tree species found in existing coffee agroforestry plots. The survey questions captured social and economic characteristics, coffee plot descriptions, including information about trees in agroforestry plots, including those with coffee as the major crop and non-coffee plots (where annual crops or tree plantations were the main productive component), the benefits that trees provide to coffee, and coffee management. Additional information on farmer perceptions of ecosystem services and disservices was captured via focus group discussions. These were also used to explore how perceptions might vary in relation to farmers' age, ethnicity and gender.

From the first survey, all the tree species on coffee farms were documented and the most dominant 25 species were selected for the second survey in May 2018. Based on the initial discussions with farmers, the perceived benefits of shade trees were grouped into 11 broad topic areas (which effectively acted as proxies for ecosystem services). These topics were tree effects on: coffee production; soil moisture, soil fertility, soil erosion, biodiversity, micro-climate regulation, wind control, frost control, effects of and on shade provision, the value of mulch provision and effects on the use of fertilizer (which relates to soil fertility and greenhouse gas emission). The same farmers involved in the previous survey were invited for the second set of interviews. There were 118 farmers from three ethnic groups Kinh, Thai and H'mong, of which were 64 men and 54 women, that were involved in the second survey. The second survey interview focused on ranking exercises [33]. Interviewees were asked to select up to 10 preferred species to grow with coffee. They must have been managing, or at least been familiar with these selected species. Pictures of both tree species and tree services were printed on cards with which farmers then ranked the performance of their selected trees for each topic area (stating whether their effect was positive or negative). Results of from individual farmer ranking of trees were recorded in the ranking sheet for later analysis. During this exercise, farmers also provided the explanation for their rankings.

A final workshop was conducted in July 2018 in Mai Son district (Son La) and Muong Ang district (Dien Bien) with 25 farmers to feedback the analysis results.

2.3. Data Analysis

The results of tree species inventory were analyzed using the principles of BiodiversityR packages in R studio and combined with Excel for visualization. Species accumulation was presented with the trendline of a data plot using logarithm function and first order Jackknife asymptote [34]. Several species accumulation analyses were made for three ethnic groups, coffee farms and non-coffee farms (for example, maize, rice, orchard plantation) to compare the biodiversity among Thai, H'mong, Kinh farms, coffee and non-coffee agroforestry plots. Coffee monoculture plots were excluded from analyses, as there were no tree species in those plots.

Following the ranking in the second survey, an analysis was undertaken using the Bradley–Terry model in R studio [35]. Ranking was converted into pairwise comparison as input data for the model.

The model was run for eleven tree services for three ethnic groups, three distances to road (near, medium and far), and gender (male and female). Species, ranked less than 10 times, were excluded from the results. The scores reflect the comparison of performance rather than the absolute values. Scores were normalized to values between 0 and 1, where 1 is the maximum value for the best tree species. Ranking data was uploaded to the online database at www.shadetreeadvice.org. This study followed the same methods as those used for other databases from Ghana [31] and China [32] to ensure that the results were comparable.

3. Results

3.1. Farm Characteristics of Coffee Agroforestry Systems

All the interviewed farmers were between 25 and 50 years old with a mean age of 39 years. Among the three ethnic groups, Kinh people had the highest mean annual income while Thai farmers had the next highest and H'mong the lowest at approximately USD 1762 per year. Mean farm size was about 1.5 ha; Kinh farmers have smaller cultivation areas compared to those of the H'mong group. Coffee was cultivated on about two thirds of their lands (approximately 1 ha on average) and the remaining areas were dedicated to annual crops for family and livestock consumption. Almost all their coffee areas were 'shaded' coffee, i.e., coffee intercropped with trees such as fruit trees, timber trees, nut trees or *L. leucocephala* (Table 1). These were considered coffee agroforestry plots. Fruits were often sold at home or on the side of the main road. Timber and coffee were collected by middlemen at home or sometimes at the local market. All the Kinh villages were near the main road, at a distance of 0–2 km. Thai farmers typically lived at distances of 0–5 km from a main road. H'mong farmers mostly lived far from main roads (5–7 km) except for the H'mong group in Toa Tinh commune, Dien Bien province, because of the newly built highway near their village.

Table 1. Social and plot characteristics of the coffee farms; data are the mean values with standard errors.

Social and Farm Characteristics	Total Population	Kinh	Thai	H'mong
Total number of respondents	124	25	83	16
Mean agricultural income (USD/year/household)	4571 ± 390	8762 ± 1286	3810 ± 324	1762 ± 276
Mean farm area (ha)	1.50 ± 0.09	1.60 ± 0.26	1.30 ± 0.10	1.90 ± 0.30
Mean number of coffee plots	2-3	2-3	2-3	2-3
Mean area of coffee plots (ha)	1.00 ± 0.09	1.10 ± 0.16	1.00 ± 0.08	1.20 ± 0.20
Mean area of agroforestry coffee plots (ha)	0.80 ± 0.06	1.00 ± 0.12	0.80 ± 0.07	1.00 ± 0.21
Mean distance to main road		0–2 km	0–5 km	0–3 km (Tuan Giao district) or 5–7 km (Muong Ang district)

3.2. Tree Species Inventory in Coffee Agroforestry Systems

Forty-seven tree species were identified during the farm inventories. These included fruit trees, timber trees, nut trees, and shade trees. All inventoried farms were located from 580 to 1000 masl. Two native timber tree species could not be botanically identified and are only referred to by their local name. Nearly half of the tree species were native (Table 2). Frequencies of tree species were calculated by dividing the number of farms a tree species was observed on by the total number of farms inventoried and expressed as a percentage. Many species were quite rare (37% were encountered on only 1% of the coffee farms while a further 37% were found on 2–10% of coffee farms). The most abundant species, found on 13–46% of farms, constituted 26% of the total species encountered. The majority of the most abundant species were commercial fruit and nut trees except for the leguminous *L. leucocephala* and *Melia azedarach* (a valuable timber tree). There were 25 exotic species out of the 48 species recorded. Longan and mango are native species, however, only grafted hybrid varieties are being planted on farms.

Table 2. Characterization of the tree species mentioned by farmers as growing on their coffee farms and observed during the farm inventory in the provinces of Son La and Dien Bien, northwest Vietnam.

No.	English Name	Scientific Name	Dominant Function	Exotic/Native	Frequencies of Species (%)
1	Longan	<i>Dimocarpus longan</i>	Commercial fruit	Exotic	46
2	Plum	<i>Prunus salicina</i>	Commercial fruit	Native	43
3	Mango	<i>Mangifera indica</i>	Commercial fruit	Exotic	42
4	Leucaena	<i>Leucaena leucocephala</i>	Shade	Exotic	23
5	Jackfruit	<i>Artocarpus heterophyllus</i>	Family consumption/ Commercial fruit	Native	22
6	Pomelo	<i>Citrus grandis</i>	Commercial fruit	Exotic	22
7	Melia	<i>Melia azedarach</i>	Commercial timber	Exotic	20
8	Peach	<i>Prunus persica</i>	Commercial fruit	Native	15
9	Macadamia	<i>Macadamia spp.</i>	Commercial nut	Exotic	15
10	Avocado	<i>Persea americana</i>	Commercial fruit	Exotic	13
11	Docynia indica	<i>Docynia indica</i>	Commercial fruit	Native	9
12	Guava	<i>Psidium guajava</i>	Commercial fruit	Native	8
13	Orange	<i>Citrus sinensis</i>	Commercial fruit	Exotic	6
14	Lime	<i>Citrus aurantifolia</i>	Family consumption	Native	6
15	Litchi	<i>Litchi chinensis</i>	Commercial fruit	Exotic	6
16	Eucalyptus	<i>Eucalyptus spp.</i>	Commercial timber	Exotic	6
17	Vernicia montana	<i>Vernicia montana</i>	Commercial timber	Native	6
18	Apricot	<i>Prunus mume</i>	Commercial fruit	Native	5
19	Tamarind	<i>Tamarindus indica</i>	Family consumption	Native	4
20	Chukrasia	<i>Chukrasia tabularis</i>	Commercial timber	Exotic	4
21	Dalbergia	<i>Dalbergia tonkinensis</i>	Commercial timber	Exotic	4
23	Manglietia	<i>Manglietia conifera</i>	Commercial timber	Exotic	3
22	Michelia	<i>Michelia mediocris</i>	Commercial timber	Exotic	3
24	Local pear	<i>Pyrus granulosa</i>	Family consumption	Native	2
25	Oroxylum indicum	<i>Oroxylum indicum</i>	Timber/flowers	Native	2
26	Lucuma	<i>Pouteria lucuma</i>	Family consumption	Native	1
27	Fig	<i>Ficus auriculata</i>	Timber/fruit	Native	1
28	Baccaurea sapida	<i>Baccaurea sapida</i>	Timber/fruit	Native	1
29	Bischofia javanica	<i>Bischofia javanica</i>	Timber	Native	1
30	Papaya	<i>Carica papaya</i>	Family consumption	Native	1
31	Star apple	<i>Chrysophyllum cainito</i>	Family consumption	Exotic	1
32	Star fruit	<i>Averrhoa carambola L.</i>	Family consumption	Exotic	1
33	Pomegranate	<i>Punica granatum</i>	Family consumption	Exotic	1
34	Indian Jujube	<i>Indian Jujube</i>	Family consumption	Native	1
35	Pine	<i>Pinus latteri</i>	Commercial timber/resin	Exotic	1
36	Styphnolobium japonicum	<i>Styphnolobium japonicum</i>	Timber	Native	1
37	Teak	<i>Tectona grandis</i>	Timber	Exotic	1
38	Alstonia scholaris	<i>Alstonia scholaris</i>	Timber	Exotic	1
39	Syzygium nervosum	<i>Syzygium nervosum</i>	Timber/leaf/flower	Exotic	1
40	Khaya senegalensis	<i>Khaya senegalensis</i>	Timber	Exotic	1
42	Dillenia Indica	<i>Dillenia Indica</i>	Timber	Exotic	1
43	Tea	<i>Camellia sinensis</i>	Leaf	Exotic	1

Table 2. Cont.

No.	English Name	Scientific Name	Dominant Function	Exotic/Native	Frequencies of Species (%)
44	Zanthoxylum rhetsa	<i>Zanthoxylum rhetsa</i>	Seed/timber	Native	1
45	Agarwood	<i>Aquilaria malaccensis</i>	Timber/resin	Exotic	1
46	Schima wallichii	<i>Schima wallichii</i>	Timber	Native	1
47	Local timber tree (mý) *		Timber	Native	1
48	Local timber tree (thro) *		Timber	Native	1

* Scientific names of those species that have not been identified.

Trees were planted in different settings such as in rows or scattered within the coffee plots or along plot boundaries. Coffee–tree intercropping practices were characterized as four common types including: coffee–fruit trees, coffee–timber trees, coffee–nut trees, and coffee–*L. leucocephala* that could be combined on one farm. In all instances, trees were planted at regular spacing in rows if there were one to two species being intercropped with coffee. Trees were planted at 5 m × 5 m for plum or mango, macadamia, *L. leucocephala*, and up to 10 m × 10 m for avocado. If more than three species were intercropped with coffee, farmers often planted them scattered between coffee rows or along the boundaries of the coffee plots. Most of the coffee–multiple fruit tree systems were found in home gardens and coffee–native timber trees were more frequently planted on plots far from the homestead. Tree products in both cases were for family consumption. Coffee with commercial trees were planted at medium to close distance to home for the ease of management, harvest and transport.

3.3. Tree Species Richness in Coffee Farms

There were significant differences in the species and area accumulations between coffee agroforestry plots and non-coffee agroforestry plots ($n = 124$, Figure 2). Non-coffee plots were fields with annual food crops or tree plantations as the main productive component. First order Jackknife asymptote showed that the extrapolated value of the total tree species richness of agroforestry coffee plots was 48. All tree species encountered during the inventories also appeared in coffee agroforestry plots. Species richness and the accumulated area of coffee agroforestry plots were almost double those of non-coffee plots as was the species richness per ha.

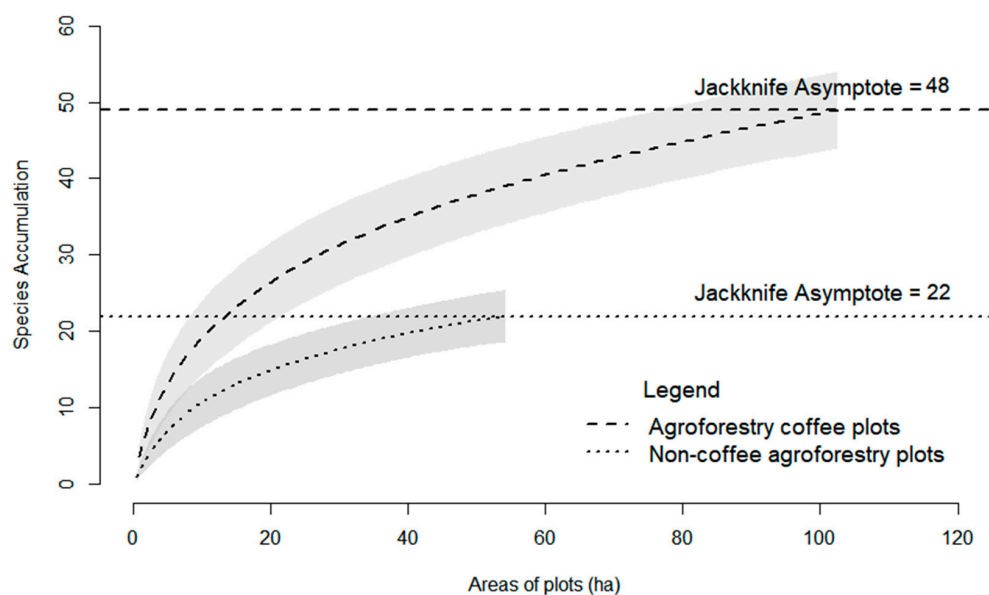


Figure 2. Species accumulations and first order Jackknife asymptotes by area from coffee agroforestry plots and non-coffee plots (orchards, annual crops, timbers).

Higher species richness was found on Thai farmers' coffee agroforestry plots compared to those of the Kinh and H'mong ethnic groups. First order Jackknife asymptotes from Kinh coffee plots was the same as that of H'mong coffee plots (Figure 3). This reflects the higher number of tree species in coffee plots of the Thai group in comparison to other groups as the Thai people live at mid-elevation which is suitable for most of the species encountered at all elevations (Table 2).

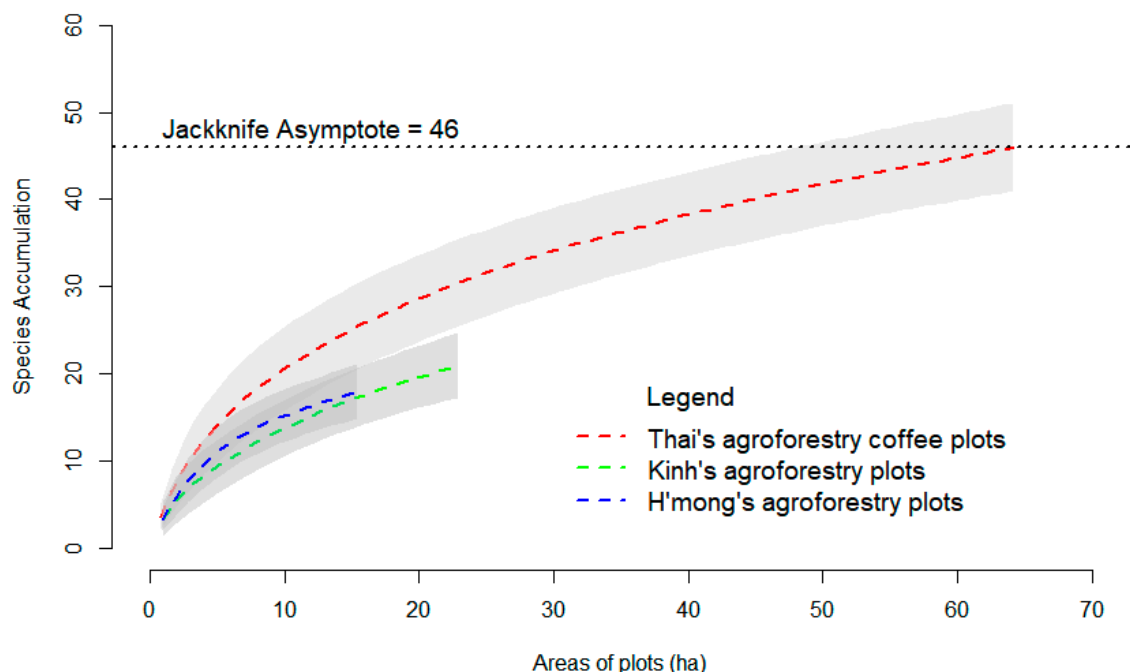


Figure 3. Species accumulations and first order Jackknife asymptotes by area from all coffee agroforestry plots of Thai, H'mong and Kinh ethnic groups.

3.4. Variation in Shade Tree Species Composition of Coffee Farms in Relation to Proximity to Main Roads

When farmers selected tree species to be intercropped with coffee in agroforestry plots, the primary factor that influenced their selection was their commercial value, i.e., their value for the provision of fruits or timbers that could be sold. There was a number of variables related to this factor including market price, proximity to market (indicated in the present study, by proximity to a main road because farmers usually sold fruits on the side of the main road). Among the three ethnic groups, the H'mong were generally at the furthest distance from the road compared with the other two groups. The Kinh people had good road networks because they live in the lower altitudes. The proximity to the road was identified as a critical factor for determining tree species selection by farmers. Fifty-two of the sampled farms were in communes near the main road (0–2 km), 54 farms were at medium distance to the main road (2–5 km) and 18 farms were far from the main road (5–7 km) (Figure 4). High-value commercial species (fruits, timbers and nuts) were commonly integrated with coffee in the close and medium distance farms (accounting for 81 and 66% of the total trees species, respectively). Commercial species were less commonly (54%) far from the main road. In these farms, more native timbers were intercropped in the coffee plots. The leguminous species, *L. leucocephala*, was more common in the farms far from the main road.

3.5. Farmer Perspectives on Ecosystem Services Associated with Trees in Coffee Systems

Farmers had in-depth knowledge of the benefits trees provided to coffee. Most of them were aware of observable ecosystem services such as reducing soil erosion, improving soil fertility, enhancing biodiversity, preventing damage from wind and frost, and providing shade and mulch.

Some ecosystem services were linked to one another, such as shade provision, mulch provision and soil moisture or frost control and wind control. Trees with big leaves and wide crowns were most

generally associated with these benefits. Interestingly, farmers had limited experience or knowledge on the effects of tree species on coffee quality. In addition, their responses suggest that they were not highly knowledgeable about the light and nutrient interactions compared to other services with more than half of their answers consisting of ‘don’t know’, indicating knowledge gaps (Figure 5).

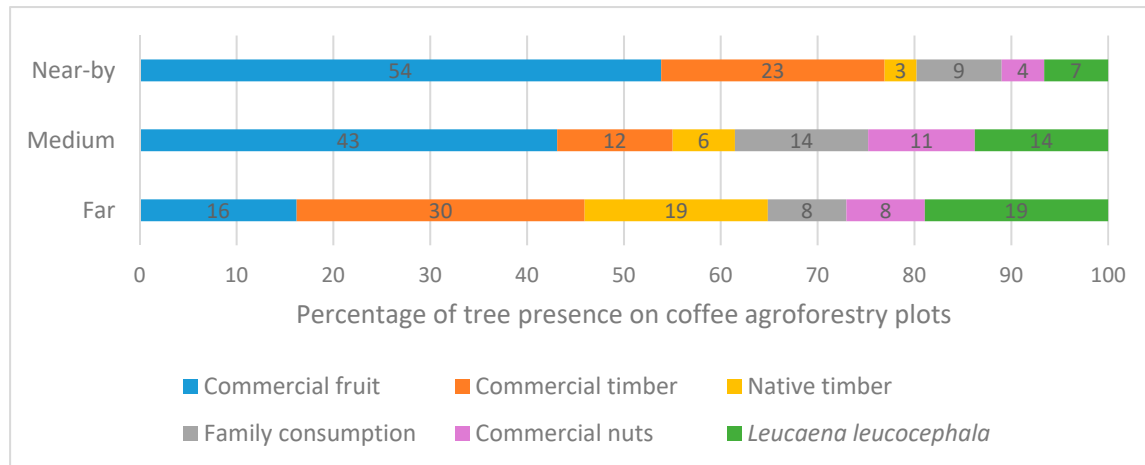


Figure 4. Percentage of tree species present in coffee agroforestry plots with respect to proximity to the road (Note: number of farmers near the road was 52, medium to road was 54, far from road is 18).

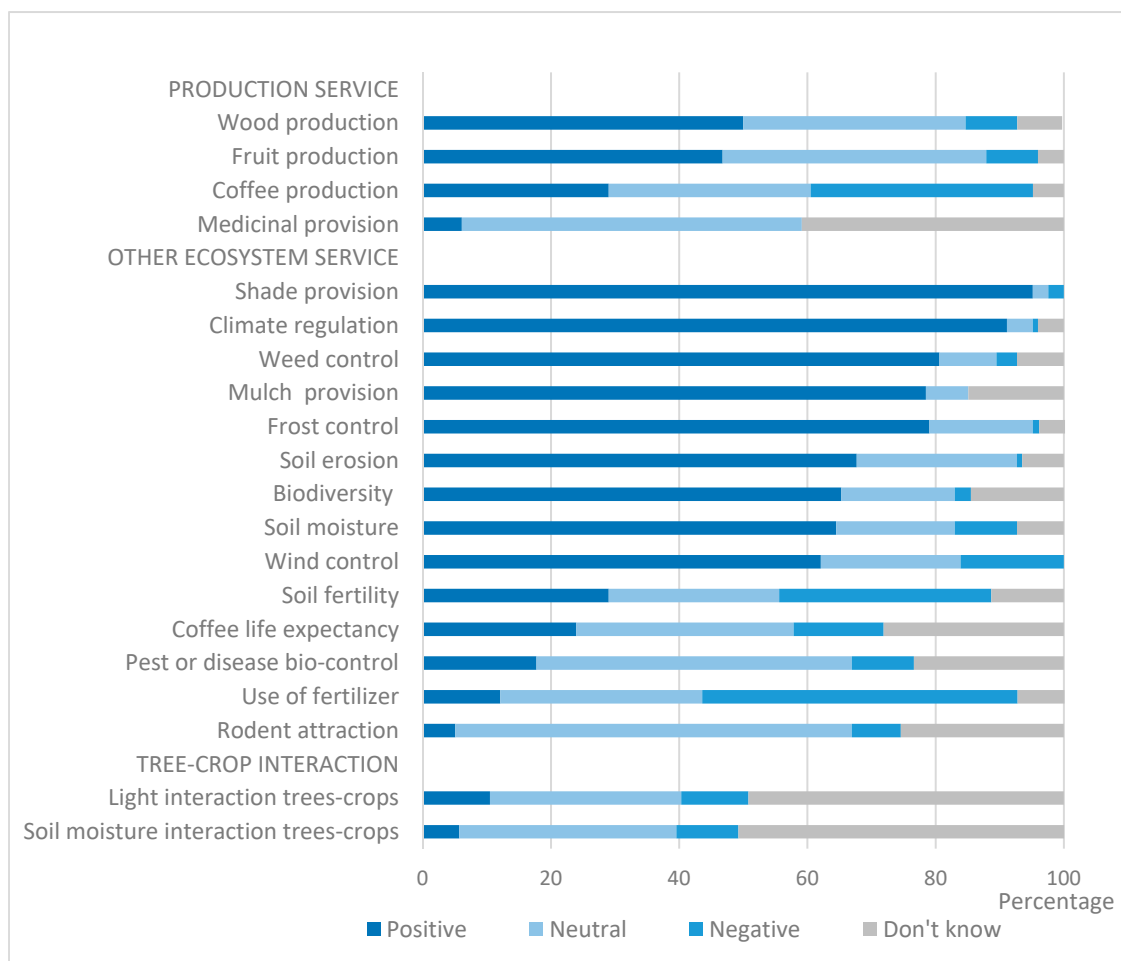


Figure 5. Farmers' perspectives on tree services to coffee in agroforestry practices in the two provinces of Son La and Dien Bien, northwest Vietnam.

When taking ethnicity into account in the analyses, the proportion of four answers were quite similar among the three ethnic groups, except for coffee production, soil fertility, use of fertilizers (Kinh farmers were more negative about these), wood production (H'mong farmers were more positive about this), biodiversity (H'mong farmers were more negative about this), and climate regulation (Thai and Kinh farmers were more positive about this) (Appendix A).

3.6. Tree Species Pairwise Ranking

Among 48 tree species encountered in coffee plots, only 25 species were intercropped in more than 2% of coffee farms. These species were selected for tree pairwise ranking exercises. Accumulated values for each species are shown in Figure 6. The leguminous shade tree species (*L. leucocephala*) was the highest valued species based on its services provided to coffee. *Dimocarpus longan* was the second highest valued species but was the most common species intercropped across coffee farms, followed by mango due to the high commercial value of their fruit. Timber trees were not preferred as farmers stated that timber trees compete for nutrients and water with coffee. Details on the ranking for each tree service are presented in Appendix B.

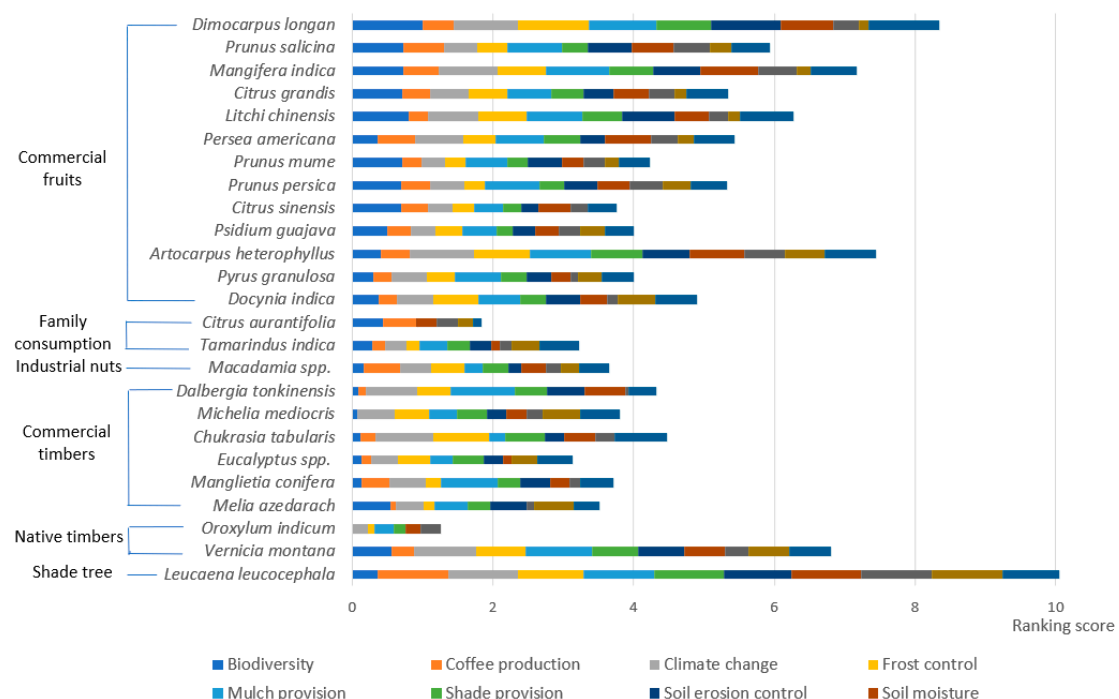


Figure 6. Accumulated tree species ranking scores for various ecosystem services based on the whole group of interviewed male and female farmers in the provinces of Son La and Dien Bien, northwest Vietnam.

Variation in how ranking changed in relation to distance to road was also analyzed and showed differences in tree ranking for coffee production (Table 3). The farmer group living near the main road ranked fruit trees such as plum and longan highly because the fruit selling prices were high, and it was easy to sell them by the roadside. They also liked the shade provided by these trees. They explained that the economic value of *L. leucocephala* was much lower than commercial fruit trees, although this tree species was good for coffee. Therefore, when their coffee farms were far from the main road, where market forces held less sway, they generally grew more *L. leucocephala* with coffee.

Table 3. Best tree species ranked by farmers with respect to the tree services provision to coffee in agroforestry practices (grouped by ethnicity and proximity to main road).

Tree Services	By Ethnic Group			By Proximity to Road			Overall Ranking
	Kinh	Thai	H'mong	Nearby	Medium	Far	
Coffee production	Leucaena *	Leucaena	Leucaena	Plum	Leucaena	Leucaena	Leucaena
Soil fertility	Leucaena *	Leucaena	Leucaena	Leucaena	Leucaena	Leucaena	Leucaena
Shade provision	Longan	Leucaena	Leucaena	Longan	Leucaena	Leucaena	Leucaena
Climate regulation	Longan	Leucaena	Mango	Longan	Leucaena	Leucaena	Leucaena
Soil moisture	Longan	Leucaena	Leucaena	Jackfruit	Leucaena	Leucaena	Leucaena
Soil erosion	Longan	Longan	Longan	Longan	Longan	Longan	Longan
Wind control	Longan	Longan	Longan	Longan	Longan	Longan	Longan
Frost control	Longan	Leucaena	Longan	Longan	Leucaena	Longan	Longan
Mulch provision	Plum	Leucaena	Longan	Longan	Jackfruit	Leucaena	Longan
Biodiversity	Longan	Longan	Mango	Longan	Longan	Longan	Longan
Use of fertilizer	Jackfruit	Leucaena	Leucaena	Leucaena	Leucaena	Peach	Leucaena

(Note: Leucaena: *L. leucocephala*, Longan: *D. longan*, Jackfruit: *A. heterophyllus*, Plum: *P. salicina*, Peach: *P. percia*; Mango: *M. indica*) (*) indicates low level of confidence in ranking results.

The leguminous tree, *L. leucocephala*, was introduced in coffee plantations first by the French since they introduced coffee cultivation in Vietnam in the 19th century. In the 1980s, *L. leucocephala* was promoted to be intercropped with coffee by Son La coffee company in Son La and Dien Bien provinces. After the company went bankrupt, farmers continued planting shade trees by themselves. More recently, some of them still keep *L. leucocephala* in their coffee plantations while an increasing number of them replaced it with commercial fruit trees. Farmers in Son La replaced *L. leucocephala* with fruit trees such as plum and longan which provide more immediate and constant income.

Ninety percent of *L. leucocephala* was found in Dien Bien province and grown by Thai farmers ($n = 29$). A few H'mong farmers also planted *L. leucocephala* intercropped with coffee and other trees. Some H'mong farmers stated that they learned the technique and took the seedlings from fellow farmers in Thai villages. Son La province is famous for fruit production while fruit tree cultivation has not been well developed in some areas of Dien Bien province despite some fruit tree support programs from the local government. Farmers in Dien Bien said that it was hard to manage fruit trees as young seedlings and fruits during harvesting season were often stolen. Harsh weather like drought and frost were also mentioned as major constraints in planting fruit trees. Most fruits for domestic consumption in Dien Bien were imported from Son La and other provinces.

Results of pairwise comparisons between men and women did not show any significant difference with the overall ranking. Men and women had quite similar average ranking for the best tree species with respect to all tree services. The main differences in their ranking were related to timber trees with respect to soil erosion, mulch provision, use of fertilizer and coffee production (Appendix C). Rankings from the three ethnic groups showed remarkable differences, mainly for timber trees and the local fruit tree son tra (*D. indica*) (Appendix D).

Longan (*D. longan*) was a highly popular fruit tree species in the northwest. From the tree inventory, *D. longan* was the most abundant species, appearing in 46% of surveyed farms. Most of the *D. longan* trees were planted by Kinh and Thai farmers. *D. longan* was highly ranked for coffee agroforestry practices because of its good services to coffee such as providing shade, litterfall to keep the soil humidity, reducing wind and frost impact.

All ranking data were uploaded to the online tool supporting decision-making process for selecting shade tree species on coffee farms together with data from other countries. The tool is available at <https://www.shadetreereadvice.org/>. Vietnamese data can be found under the Vietnam country category, northwest region, Arabica variety and medium zone. After the users select the ecosystem services that they wish to prioritize, the tool produces outputs suggesting appropriate shade tree species to be considered to be integrated into their coffee practices.

4. Discussion

4.1. Tree Diversity in Coffee Agroforestry Systems

Shaded coffee systems were well recognized for biodiversity enhancement according to the farmers' perception. Tree species richness from agroforestry coffee plots was almost double that of non-coffee plots, supporting the notion that shaded coffee systems have higher tree diversity compared to other agricultural land uses [23]. The highest diversity of trees found on coffee plots were associated with Thai farmers (Figure 3), which can be explained by the favorable conditions of their mid-elevation location for various tree species compared to other two groups. Thai people generally live at a medium elevation from 600 to 800 m and are near or at medium distance to main roads.

Among 48 recorded species from the tree inventory, 10 species are the most abundant as being planted in more than 10% of total inventoried coffee plots. This is relatively low compared to the 162 tree species found in the Yunnan, China [32], 165 tree species in Mount Kenya [36] and 100 species associated with coffee in Muranga, Kenya, 29 of which were sufficiently abundant to be ranked [28]. However, this finding was similar to the 36 species that farmers had knowledge of in coffee farms in Costa Rica [27] and the number of species found by Nyaga et al. [37] in agroforestry in the Rift Valley in Kenya with 44 species (55% native). However, the primary functions of trees in Vietnam were commercial fruits with a ready market while the most abundant species in the Rift Valley in Kenya were firewood and fast growing fodder or fertilizer species [37].

4.2. Tree Ranking and Farmer's Perception on Tree Services or Disservices

In northwest Vietnam, farmers did not like planting timber trees with coffee. They only planted timber trees when they had no other choices for fruits (either because of unsuitable conditions or distance from the market). Farmers' ranked timber trees lowest indicating competitive rather than complementary relationships with coffee. This was consistent with the tree frequencies (Table 2) where timber species appeared in less than 6% of surveyed farms. Farmers were knowledgeable about the benefits that trees can provide to coffee as documented in other continents [33,38]. In this study, farmers could confidently describe the effects of trees on climate regulation, soil erosion, shade provision, mulch provision, frost and wind control.

Unlike in the Central Highlands of Vietnam where coffee was blamed for deforestation [39], in the northwest, most coffee farms were established on annual crop land or fallow land [10]. Therefore, farmers could clearly explain the benefits, based on direct observation, of integrating trees on their coffee farms on steep slopes, such as soil becoming soft and moist, and having darker brown color compared to a more yellow color in the past. Farmers were much less clear about tree shade interactions with the coffee plants, particularly with regard to the competition between coffee and trees for light and water (Figure 5), although they were aware that 'too much' shade made coffee beans take too long to ripen, and that the coffee produced fewer cherries but the size of the cherries was bigger. Coffee quality remains a big knowledge gap because farmers do not drink the coffee they produce. These are areas where better information about the effects of different shade species on the quality of the coffee may lead to the greater diversification of shade trees—provided that quality influences the price farmers receive for their coffee.

4.3. The Relevance of Tree Knowledge and Tree Biophysical Suitability

Nitrogen-fixing species are common in many coffee regions of the world such as *Erythrina* spp. and *Inga* spp. in Central America, although they have no timber values [40]; and *L. leucocephala* was ranked as best species for most ecosystem services, but was only planted in 23% of coffee fields, mainly in Dien Bien. As observed by farmers, *L. leucocephala* grew well with coffee and provided good shade as its leaf size was not too small or too large. Furthermore, *L. leucocephala* leaves were soft, which was good for soil fertility because they decompose quickly. Although legume species are good for coffee, this also depends on the management of legume trees on farms [12]. Farmers in Dien Bien

expressed their concern about too much shade from *L. leucocephala* trees. Coffee density under shade was not discussed with farmers while it appeared as a factor significantly influencing performance. Medium intensity coffee management under shade is recommended in Central America [38].

Fruit tree cultivation in coffee farms is also popular in other countries thanks to their high profit. Farmers in Yunnan ranked fruit trees including *D. longan* quite high [30]. *Dimocarpus longan* is restricted to elevations lower than 600 m whereas Arabica coffee is suitable at elevations of 500 masl and above. Thai and H'mong farmers ranked *D. longan* as a good species for some ecosystem services and they expressed the wish to expand coffee–*D. longan* systems if they had available land. This raises a concern about the suitability of *D. longan* at higher elevations, as it may lead to the low productivity of the trees and integrated coffee–*D. longan* cultivation—although farmers stated that *D. longan* has a large crown and wide root system which negatively interact with coffee. The farmers' selection of tree species in coffee agroforestry systems was highly influenced by the economic benefits of intercropped trees and market access, particularly the proximity of farms to a main road. The oversupply of *D. longan* could lead to market price reduction in the near future. Moreover, the farmers' choice of trees were just a few species (*L. leucocephala*, longan, peach, plum, jackfruit), and hence the low biodiversity of the coffee landscape can be foreseen.

Farmers ranked timber species as the worst species to integrate in coffee plots. They explained that timber trees often compete with coffee for water and nutrition, and provide heavy shade and hence were not good for coffee. Poor quality road networks make farmers reluctant to grow timber trees as the transportation costs are high. This is quite similar to Central America where timber trees are also less common in coffee farms although they can provide additional values for farmers [41]. Compared to fruit trees, timber trees provide long-term benefit and could be considered as analogous to a savings bank account for the next generation. This suggests a need for further studies to focus on the economic benefits and trade-offs associated with integrating various types of trees in coffee farms, such as legume trees for shade and fertility versus timber or fruit trees for their commercial value.

4.4. Gender, Ethnicity and Tree Selection

Both men and women farmers from the three ethnic groups: Kinh, Thai, H'mong, ranked *L. leucocephala* as the best tree species providing multiple services to coffee. Overall ranking shows that the most preferred options were *D. longan* or plum and jackfruit if the farms were close to the main road. *Leucaena leucocephala* was preferred if the farms were further away from the road. Thus, market access appears to be a main driver of tree species selection. Moreover, coffee was produced only for trade, as the farmers did not consume it themselves and hence had no knowledge about tree species or the management effects on the quality of the final product; that is, the cup of coffee is mostly consumed in consuming countries. In this commercial system, market factors seemed to be the most important consideration rather than ethnicity, gender or the local knowledge about different tree species.

5. Conclusions

This study suggests that integrating trees into monoculture coffee systems can bring multiple benefits to the environment and rural livelihoods in northwest Vietnam. From the field surveys, it was observed that most of the smallholder coffee area was under agroforestry, but highly dependent on plot location, ecological suitability and market access. The tree diversity of coffee agroforestry plots were double those of agroforestry with annual crops, orchards or timber plantations. There were observable differences between the three ethnic groups. Thai farms had higher tree species richness in comparison with Kinh and H'mong groups—but it was not clear the degree to which this was driven by cultural rather than other contextual factors (such as proximity to roads and elevation). Commercial fruit trees were more common when farmers lived near or at a medium distance to main roads. Timber trees and a legume tree, *L. leucocephala*, were more common on coffee farms which were far from the road.

Farmers had detailed knowledge about observable tree services such as soil erosion control and mulch provision but they appeared to lack knowledge about the effects of shade trees on soil

fertility, pest and disease control, and interestingly, on the competition or complementarity between coffee and trees in respect of light and water capture. This is where integrating local knowledge and scientific knowledge can provide richer advice to farmers on selecting appropriate tree species for their coffee farms.

By uploading the data from this research to the online tool <http://shadetreeadvice.org>, the information is available to help farmers, researchers and policy makers to choose suitable tree species according to the services that they can provide. Further improvement of the tool could include a focus on management aspects with farmers ranking additional information, such as the labor requirement for species associated with the timing and severity of tree pruning. This could be used to create a more comprehensive knowledge management system that goes beyond tree species selection.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

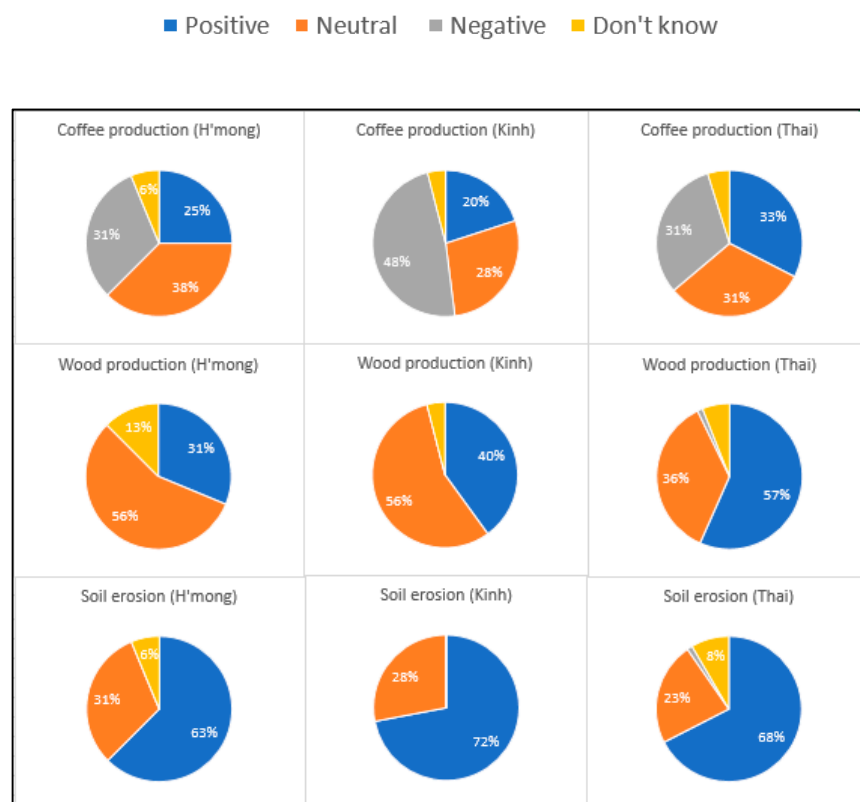


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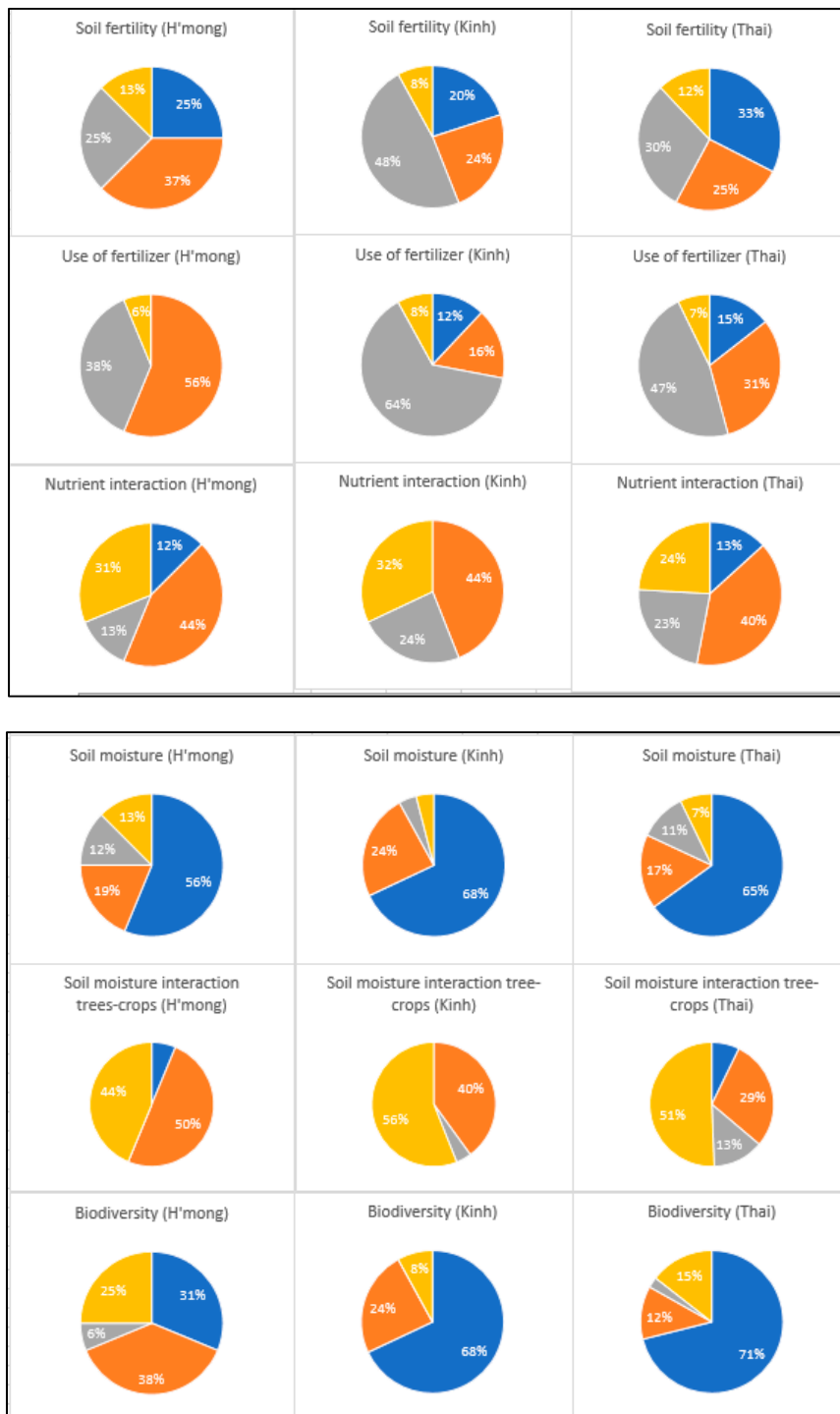


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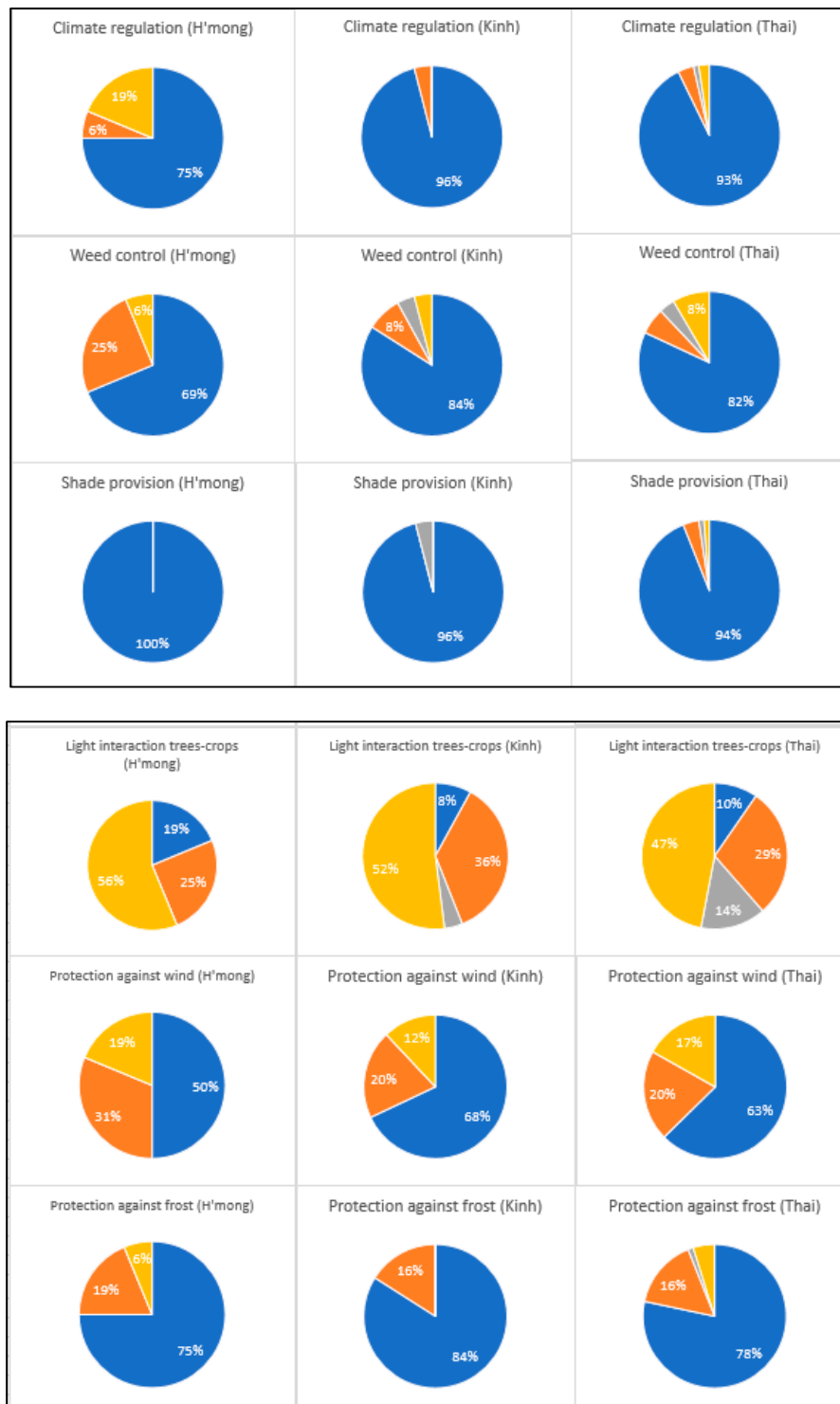


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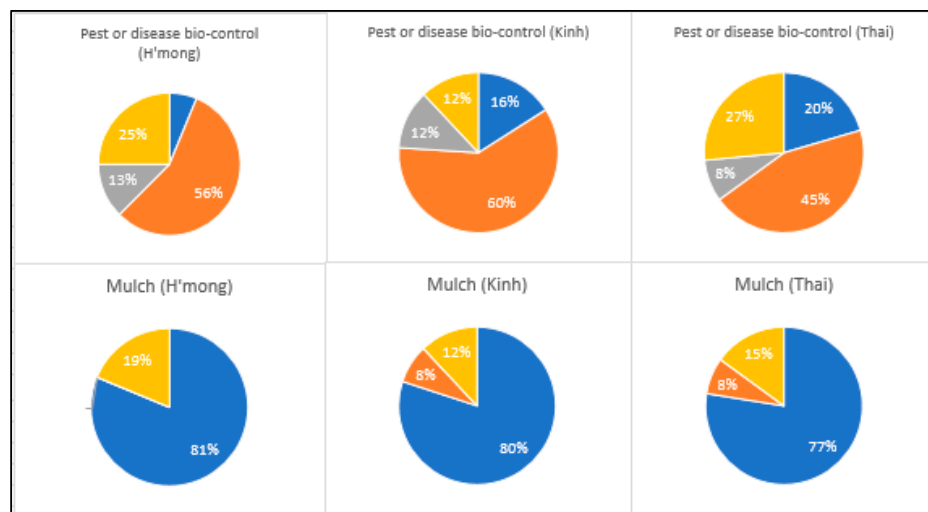


Figure A1. Farmers' perception of tree services for coffee in coffee agroforestry systems by ethnicity.

Appendix B

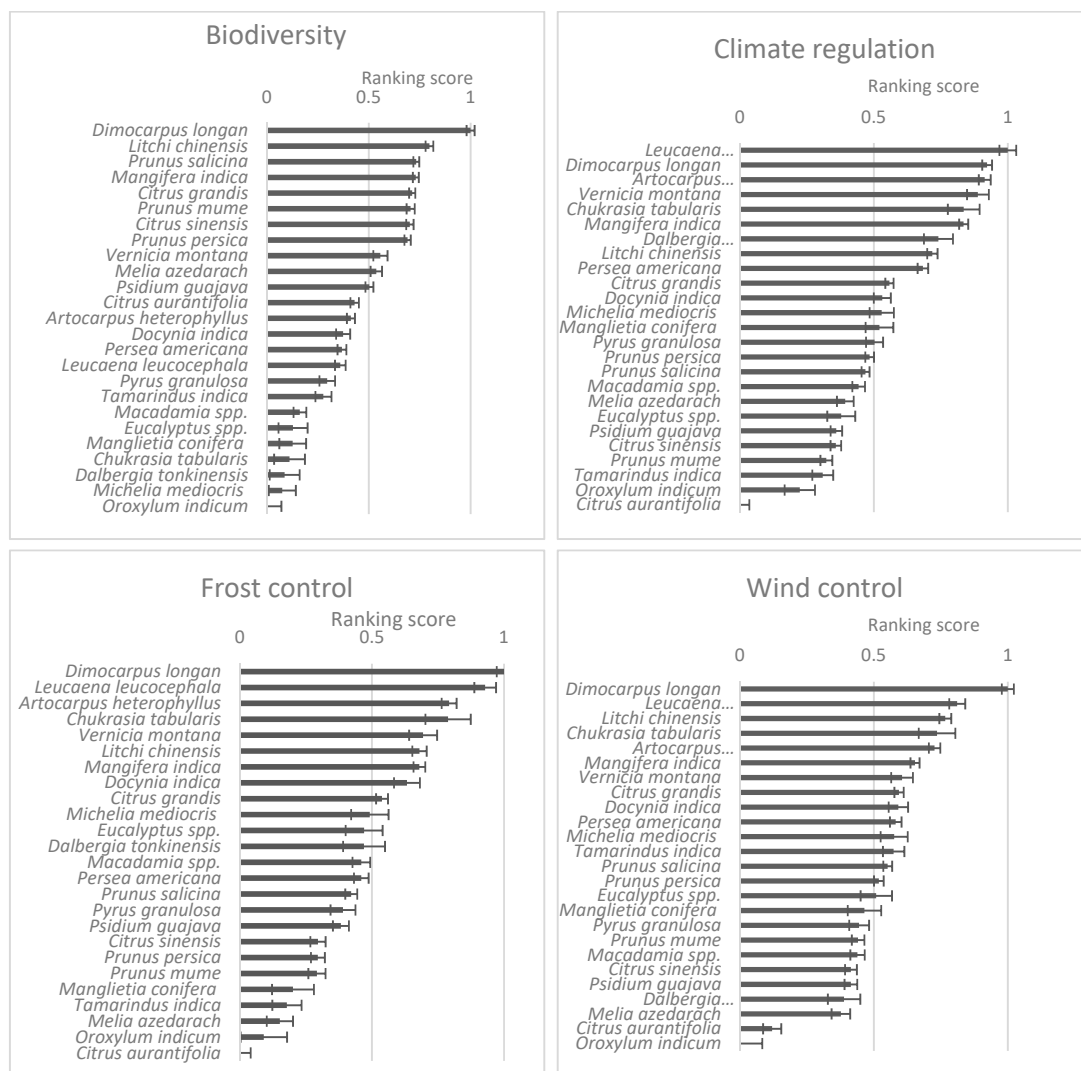


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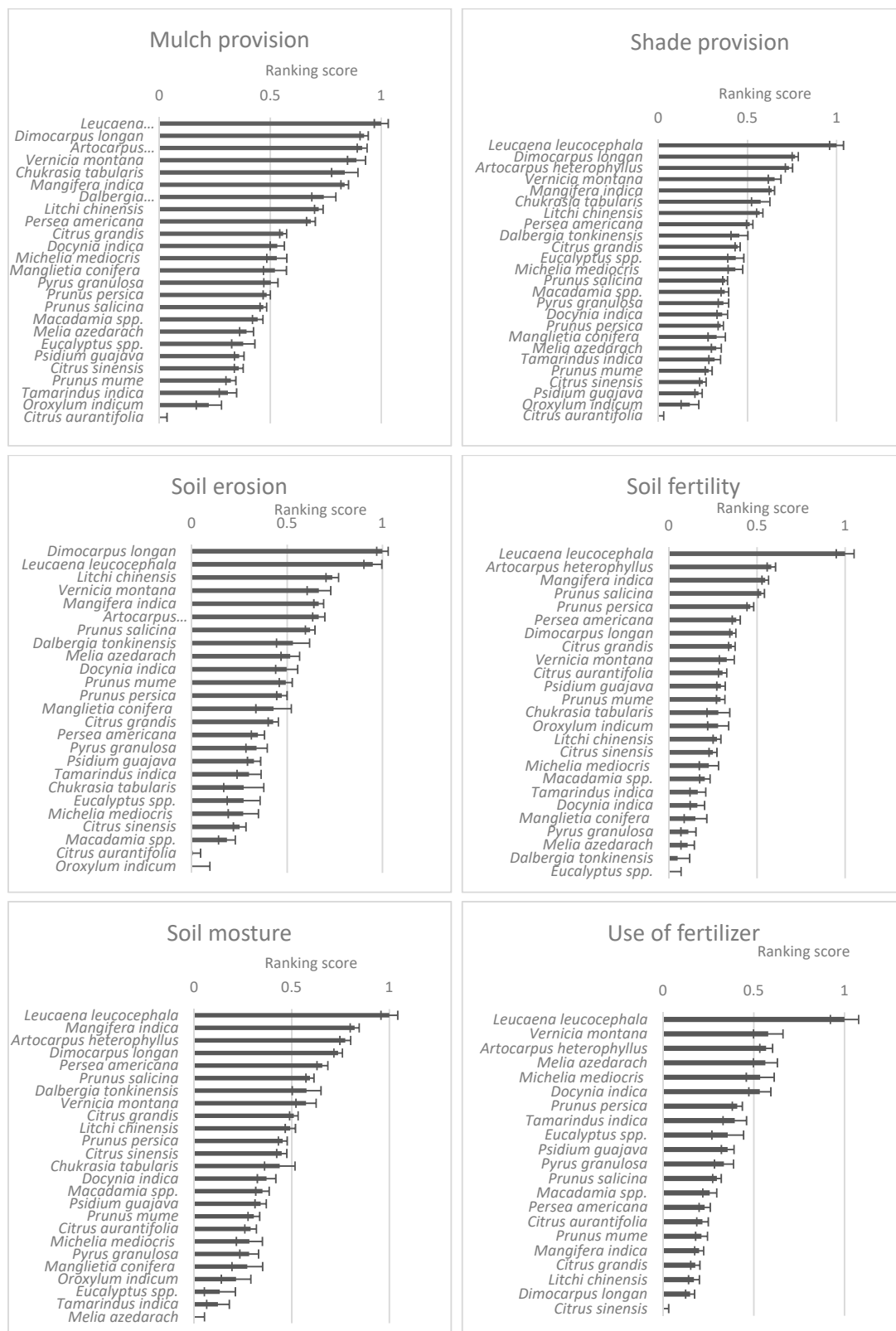


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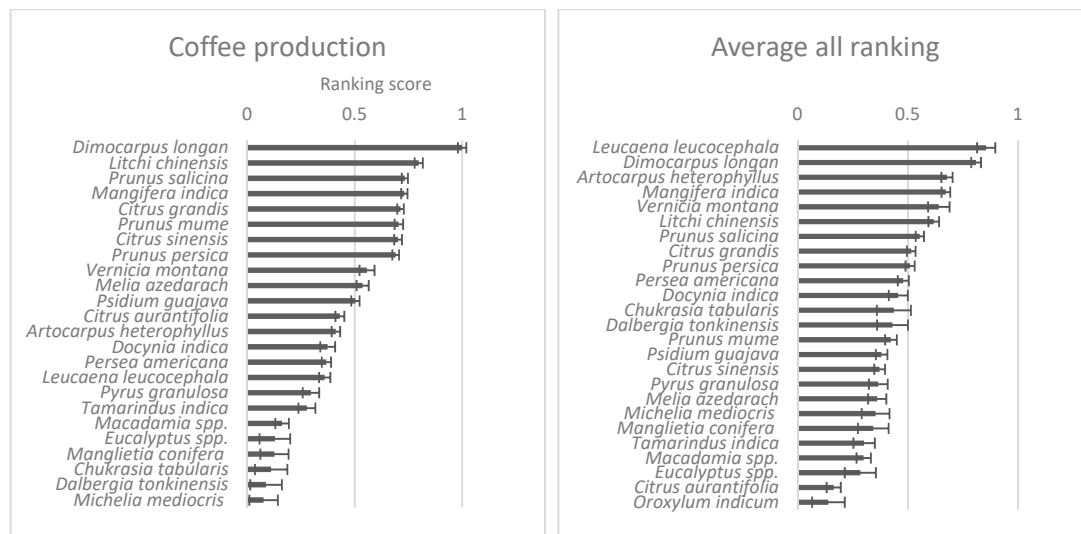


Figure A2. Pairwise ranking of tree species contributing to various tree services in coffee agroforestry systems with all groups combined.

Appendix C

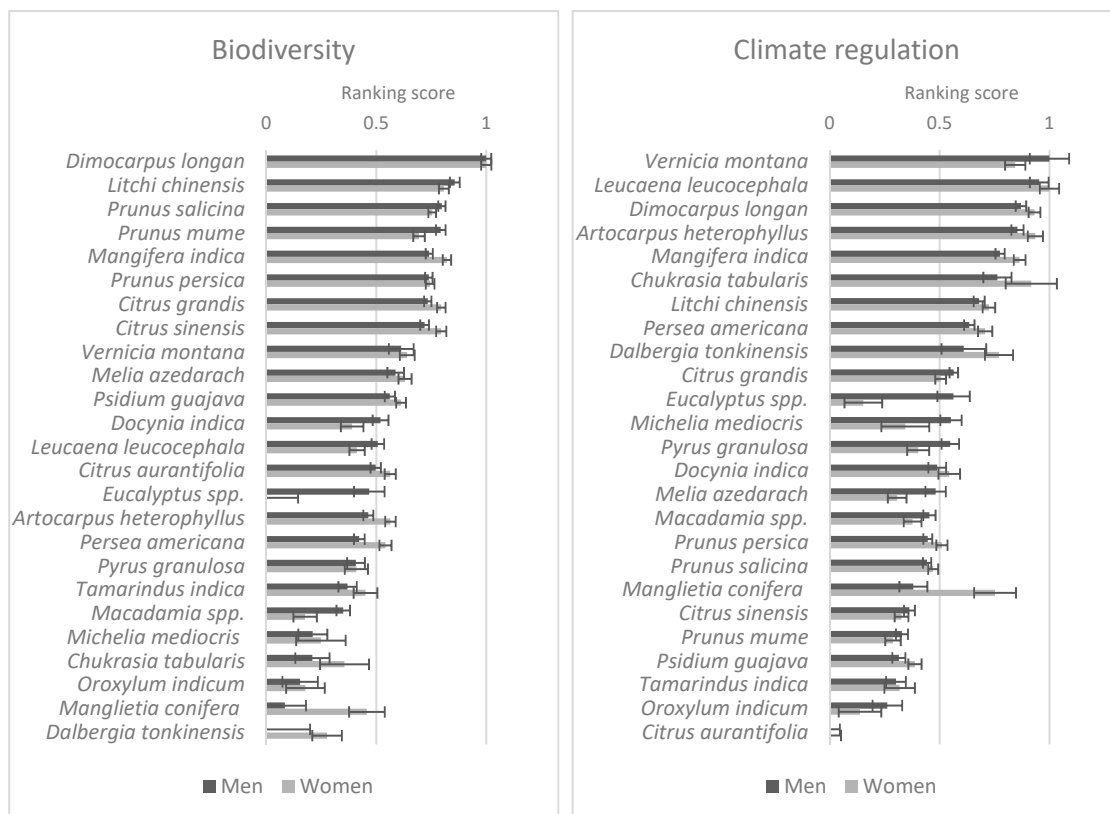


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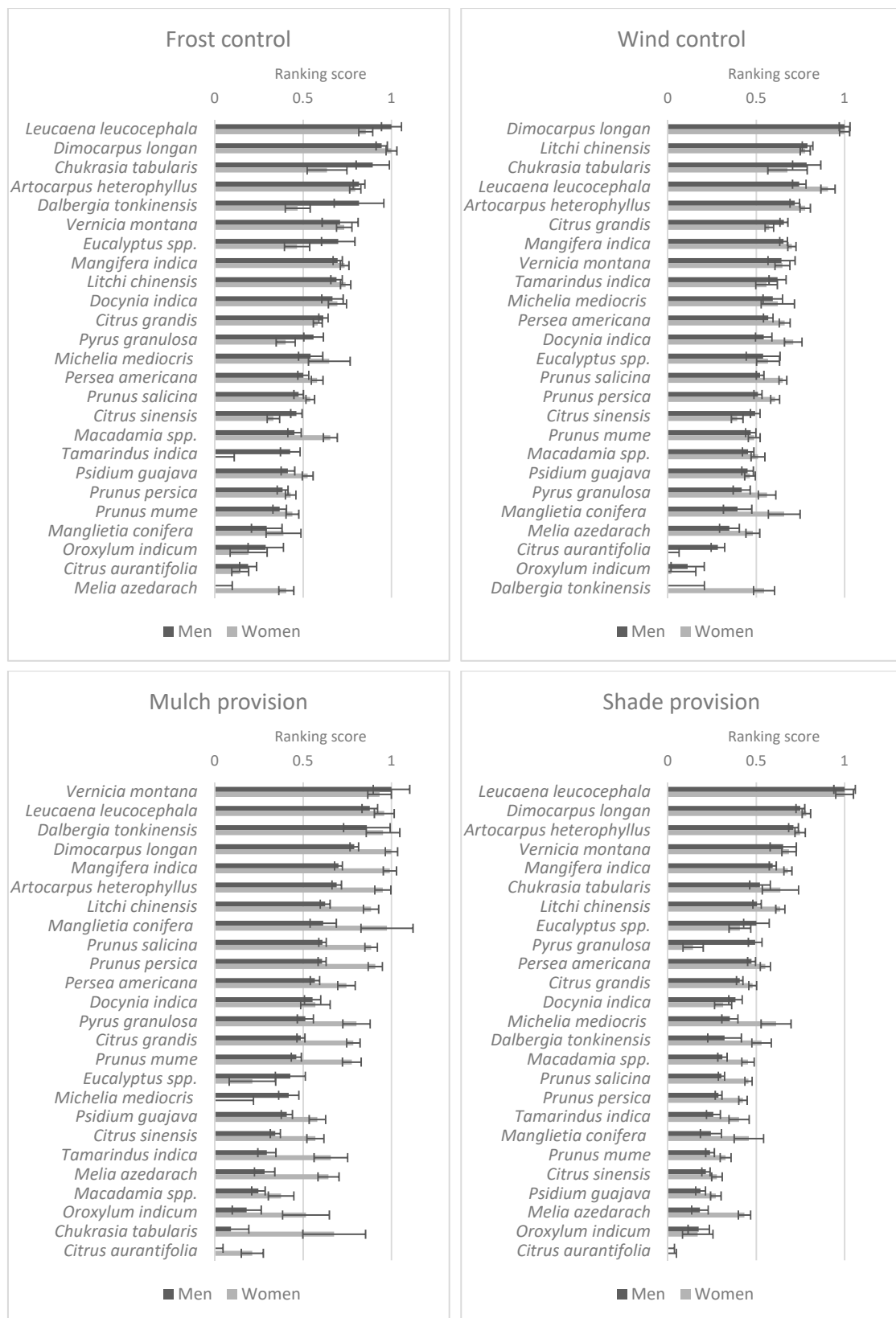


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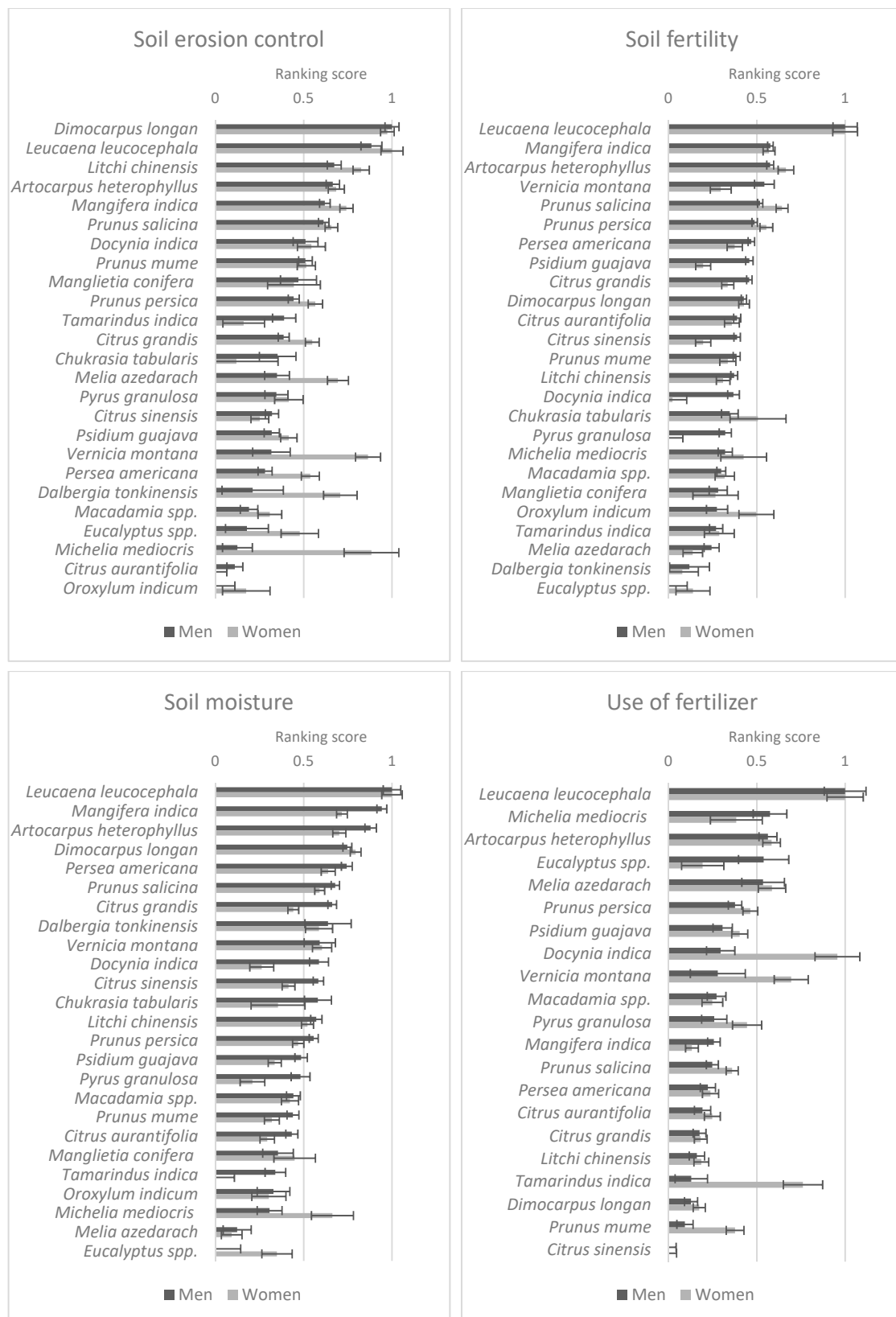


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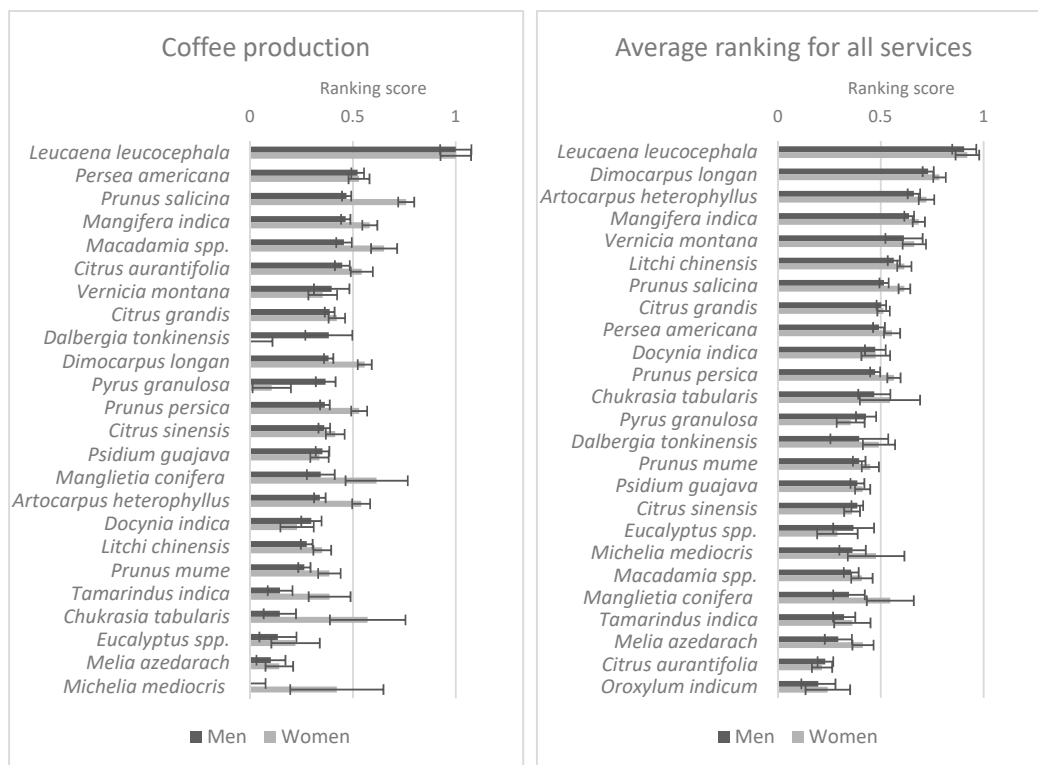


Figure A3. Pairwise ranking of tree species contributing to different tree services in coffee agroforestry systems by gender.

Appendix D

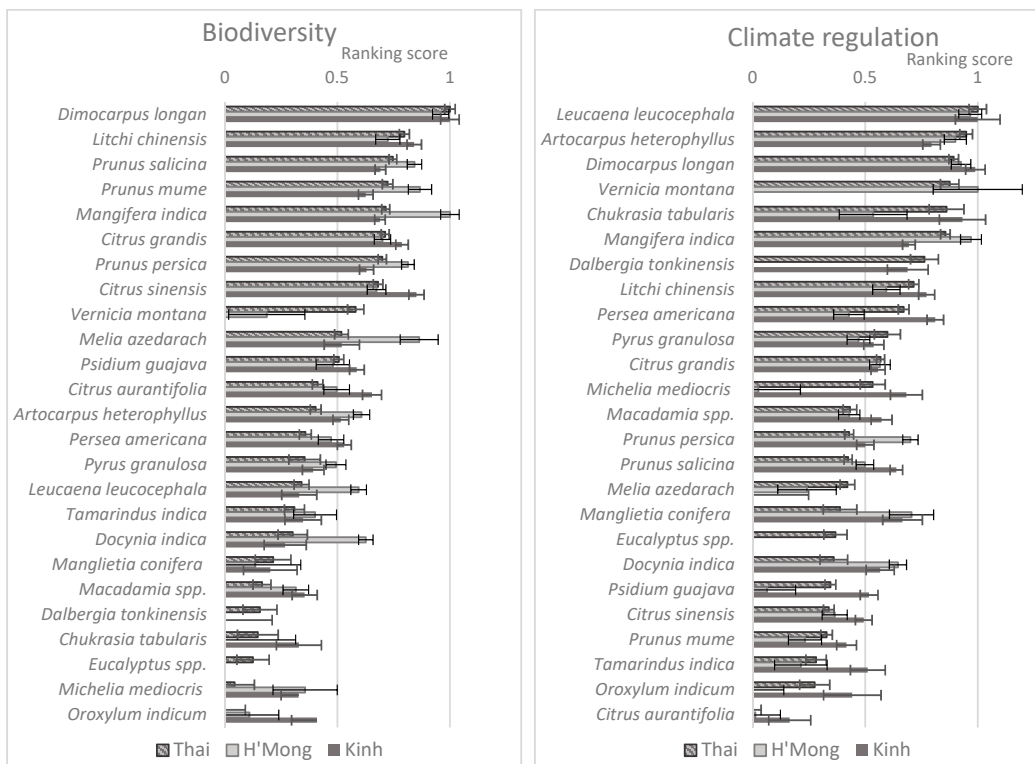


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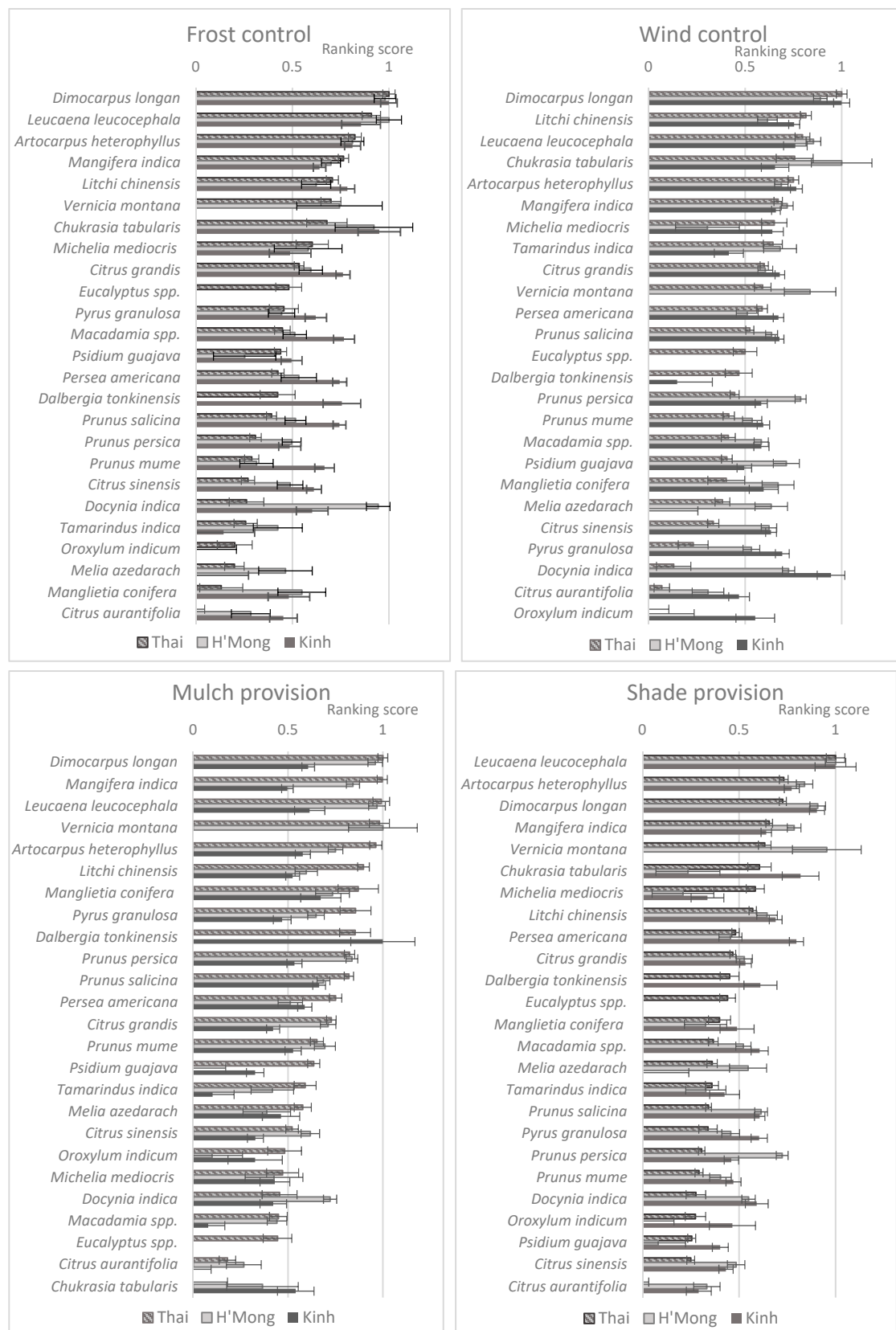


Figure A4. Cont.

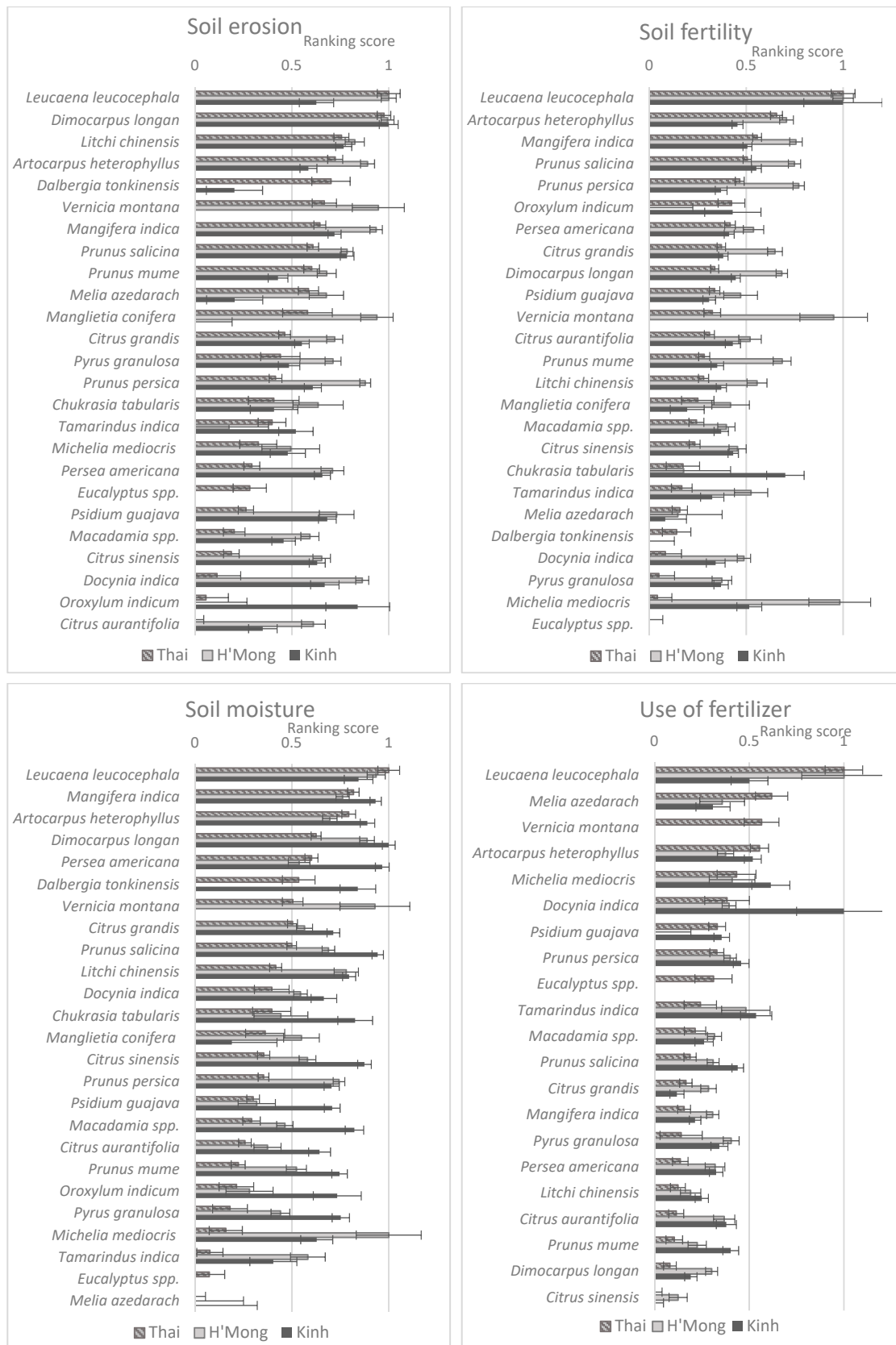


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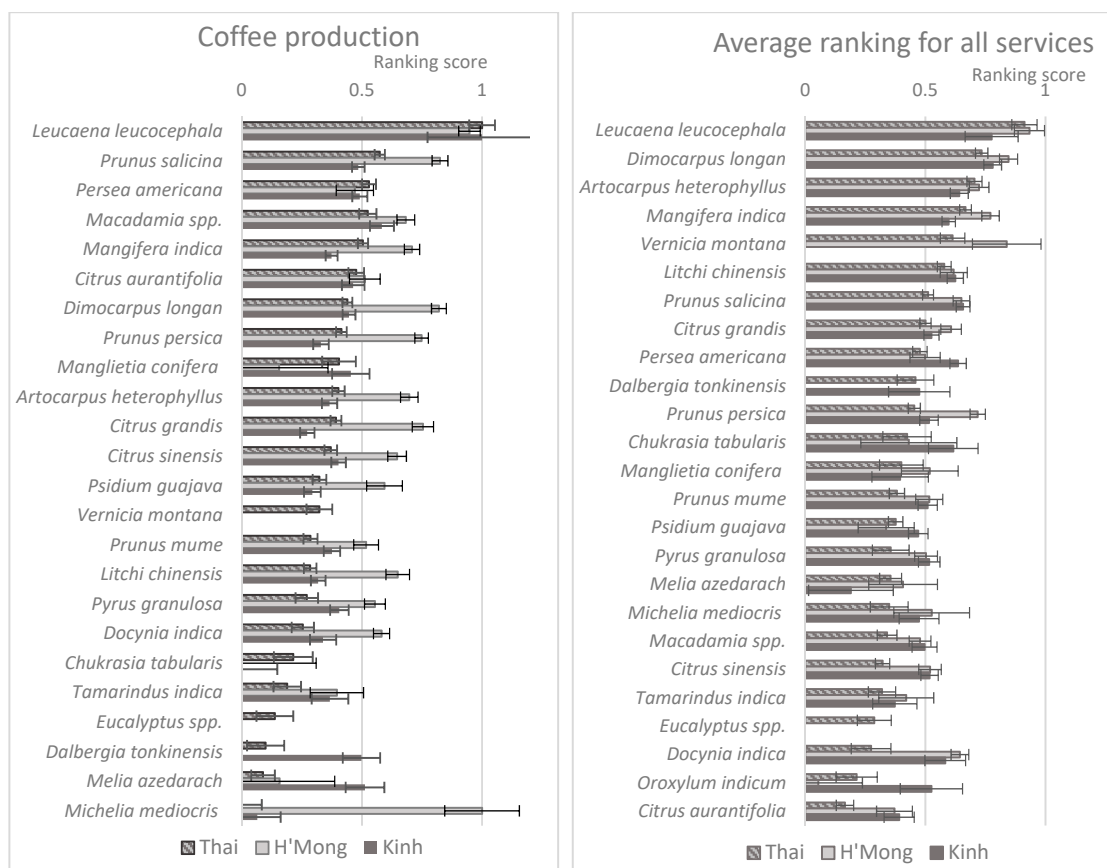


Figure A4. Pairwise ranking of tree species in coffee agroforestry systems by tree service and by ethnic group (Thai, H'Mong and Kinh).

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